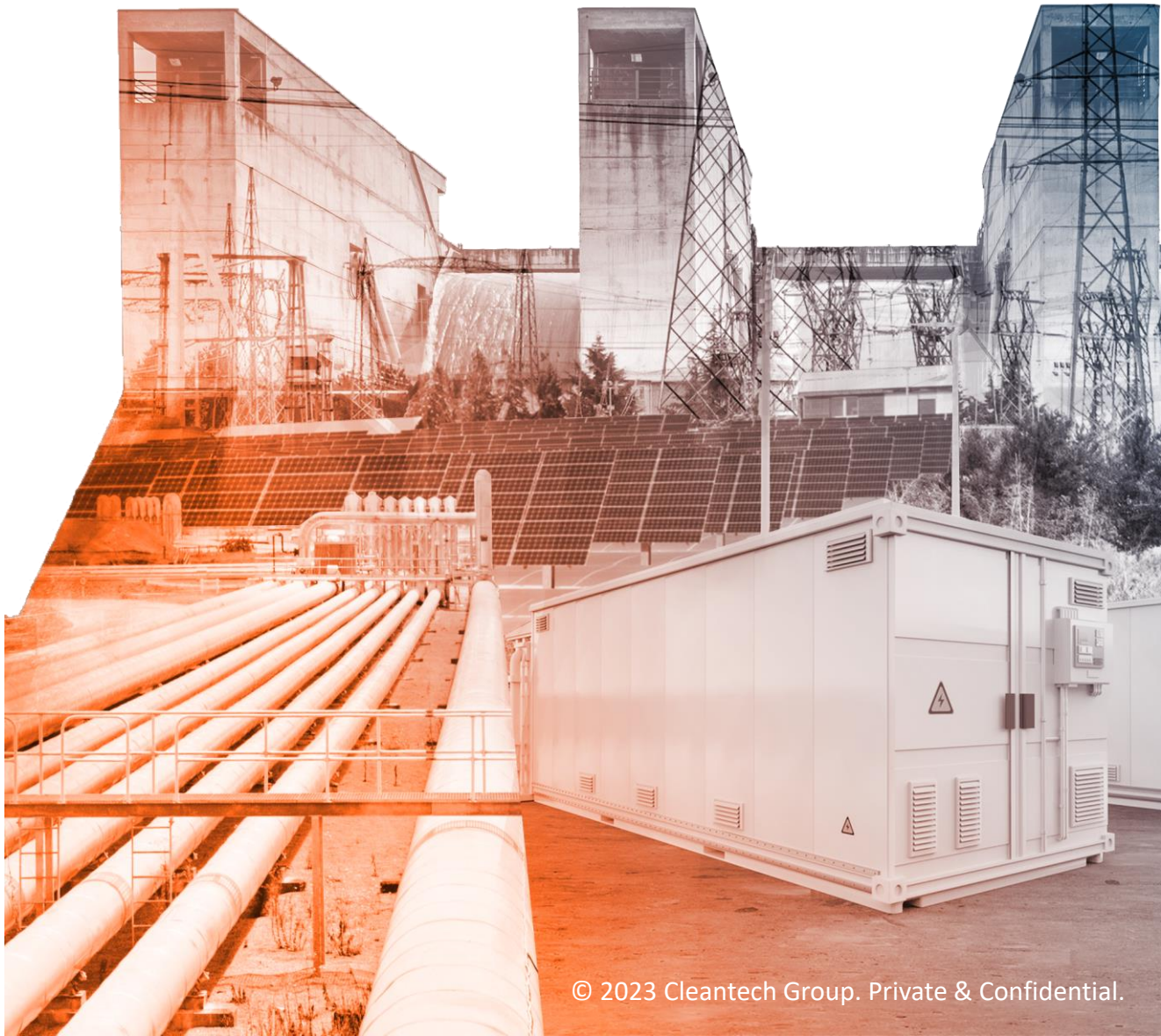
Cleantech Group

Spotlight

Energy & Power

Residential Heat Pumps

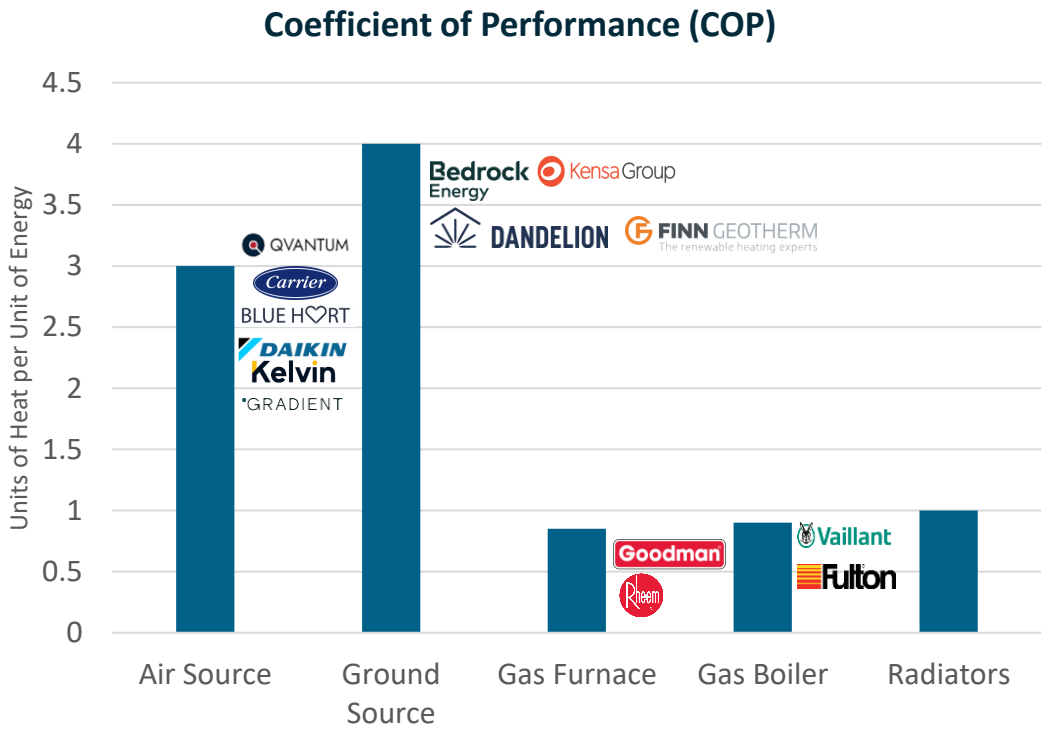
December 2023



Executive Summary: Residential Heat Pumps

Heat pumps are the primary means to decarbonize residential CO2 emissions

- Heat pumps are electrical appliances that transfer heat to achieve a desired temperature: **ground source** heat pumps move heat from the earth while **air source** heat pumps move heat from ambient air inside or outside the home
- 53% of residential emissions come from heating and cooling, heat pumps directly address both without the need for separate heating and cooling hardware (C2ES)
- Over a 15 year product life cycle, a heat pump produce **93% less greenhouse gas emissions** than boilers and furnaces and are **3-4x more energy efficient** (IEA)
- Despite their comparative efficiency, heat pumps are still 5-20% more expensive over a 15-year life cycle due to high installation costs (ground source), regional operating issues (air source), and manufacturing bottlenecks (both)
- Legislation has increased demand through boiler/furnace bans (Germany), heat pump mandates in new builds (U.S., China), preferable electricity rates (Germany, Holland), and installation rebates
- Ground source must reduce installation costs to compete in residential heating
  - AI-assisted planning (**Genius**), improved boring technologies to reduce installation cost/timelines, district systems to spread installation cost over several customers
  - Initial clients are new builds and district systems in the coming years, reduced drilling costs will open the single-family home market
- Air source has key advantages in urban homes, must stack technical improvements to compete in cold, single-family homes
  - Digital consultation tools (**Woltair**), improved refrigerants (**BlueHeart, Flow**), and high efficiency components (compressors, valves, coils, and waste heat utilization)
  - Greatest success is in urban apartments, poor performance in cold climates currently limits installations in single-family homes



Graph depicts the Coefficient of Performance (COP) of several different heating systems. COP is a measure of HVAC efficiency using the following formula: Output Capacity (BTUs/Hr) / Power Input (Wattage).

Source: Cleantech Group

Cleantech Group

Residential Heat Pumps: Setting the Stage

Decarbonizing residential heating is within reach with residential heat pumps, but cost remains the issue

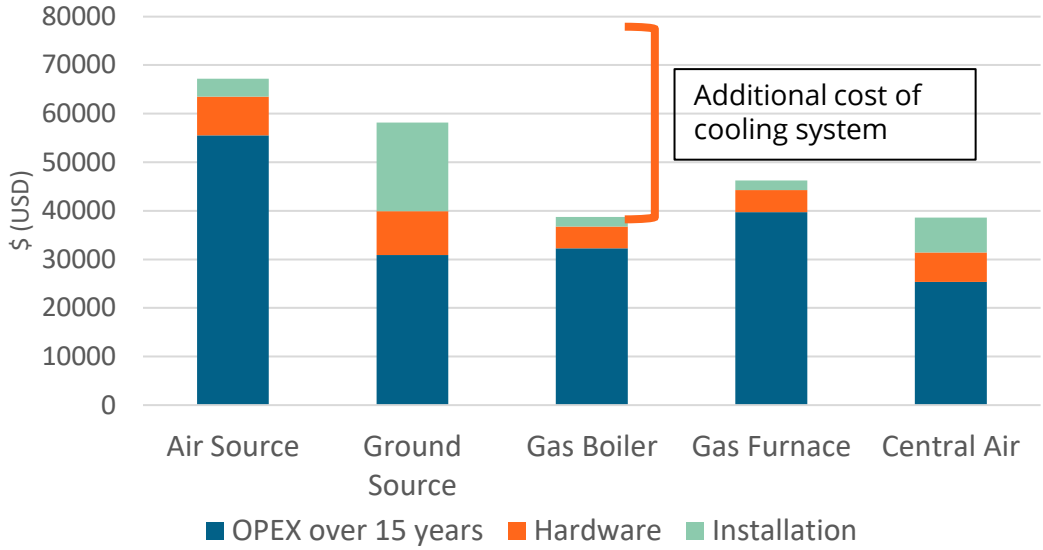
Status Quo & Global Challenges

- Heating in buildings produced 4 gigatonnes (Gt) of CO2 emissions in 2021 – 10% of global emissions (IEA)
- Residential heating and cooling produces 17% of US carbon emissions annually
- Fossil fuels, mostly natural gas, currently meet > 60% of global heating energy demand
- By 2050, 2.6B people globally will live in regions requiring heating and cooling with 47% of the world relying on natural gas for heating
- Combustion-based heating creates pollutants (sulfur dioxide, nitrogen oxides) and particulate matter that contribute to respiratory health issues, smog, and acid rain
- Industry standard refrigerants are up to 10,000 times worse for the atmosphere than CO2
- Recent conflicts such as the Russia-Ukraine War have created a high price environment and supply concerns for natural gas, particularly prevalent in Europe

Impact

- A heat pump, ground source or air source, creates 93% less greenhouse gas emissions over its lifetime than gas furnaces and boilers (IEA)
- At current heat pump installation rates, residential heating/cooling CO2 emissions will decline up to 40% by 2030, further with improved refrigerants and renewable electricity
- **Heat pumps replace the need for separate heating and cooling systems, reducing expenditures on furnace and air conditioning systems**
- Compared to boilers and furnaces, air source heat pumps are 3x more energy efficient while ground source heat pumps are over 4x more energy efficient
- System can easily be connected to a distributed renewable system, reducing grid load and increasing savings on electricity
- Combined with renewables and home storage, heat pumps can offer a 100% renewable solution

Residential Heating & Cooling Cost over 15 Years



Graph depicts costs for hardware, installation, and operational cost (including average repairs over 15 years, and averaged energy costs for heating and cooling) of a 2,500 square foot home in New York state

Source: Cleantech Group

Cleantech Group

Residential Heat Pumps: Reducing Capital Costs and Operational Efficiency

Air Source is optimizing valves and compressors while ground source cuts drilling costs with experimental technologies

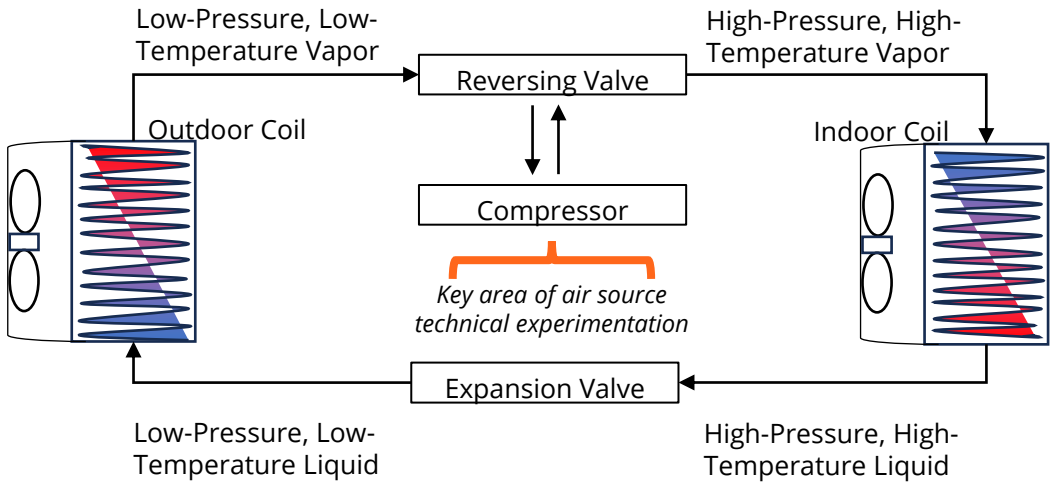
Heat Pumps' localized challenges: climate, geology, & installation

- Costs of heat pump installation still high compared to competing technologies
- Both heat pumps face supply chain issues as manufacturing pace is behind consumer demand
- Installations companies have been slow in adopting heat pumps and struggle intensely with planning timelines, local restrictions for ground source
- Air source heat pumps are limited by size of residence, cold climates
- Ground source heat pumps are limited in the available land to drill, geological composition, competition for boring technologies, and cost of drilling

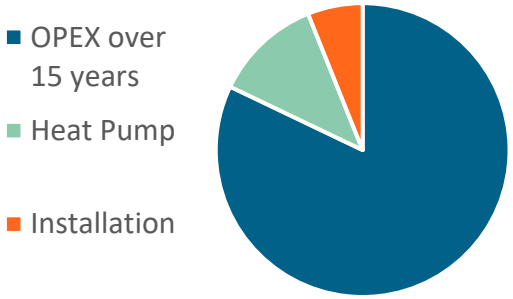
Air source improving efficiency, ground source tackling drilling cost

- Software creating digital maps of subsurface geologies, connecting supply chains, digitizing surveying (**Genius Energy Labs**, **Woltair**, **Lun**) reduce installation costs
- Air source heat pumps must stack innovation in several areas to reduce operating costs, improve efficiency, and expand heating range
  - Improved refrigerant technologies including thermoacoustic (**BlueHeart**), liquid desiccant/water (**Daikin, Mojave**), or carbon dioxide (**Flow**) reduce cost and emissions
  - Thermoelectric semiconductors (**Phononic**) instead of compressors, modular transformers (**Qpinch**) may reduce heat loss and reduce electricity consumption
  - Thermostatic expansion valves, variable speed blowers, improved coil/motor design, two-speed compressors, atomizers all improve heating range, performance in cold
- **Reducing geothermal drilling costs through down the hole (DTH) technologies, borehole depth, and district heating** to spread cost of drilling over communities
  - Utilizing DTH hammers, percussive instruments to break up earth during drilling, has tripled drilling efficiency (**Numa**, **Hydrovolve**)
  - Varying drilling depth, mostly to account for energy demands (**Dandelion Energy** – 200 feet, **Bedrock Energy** – 2,000 feet)
  - Using existing foundations, reducing land footprint (**Celsius Energy**)

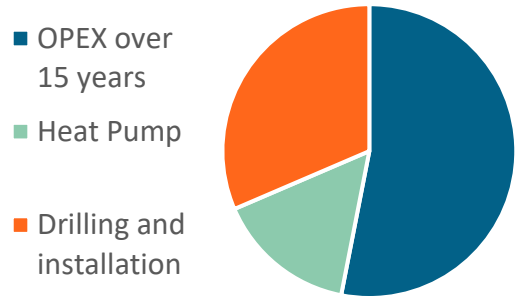
Heat Pump Diagram



Air Source Cost



Ground Source Cost

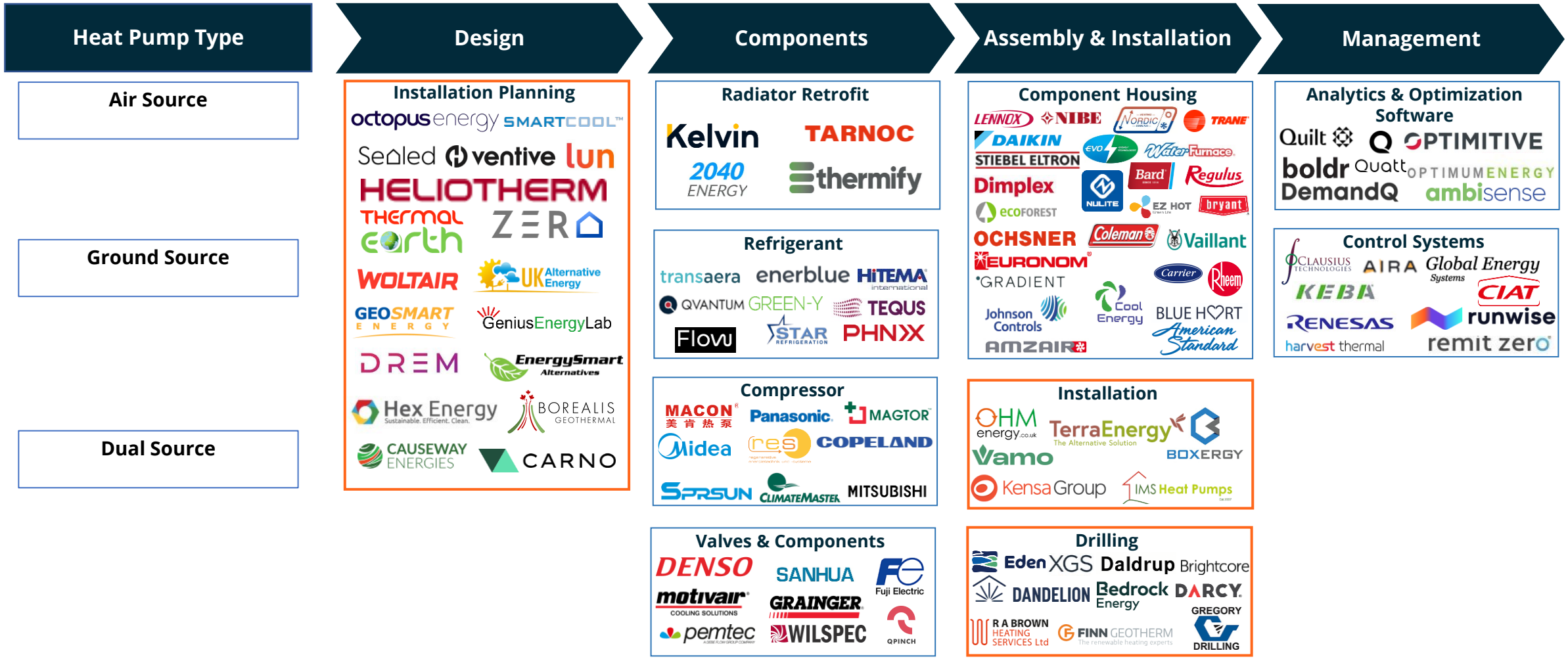


Graph depicts costs for hardware, installation, and operational cost (including average repairs over 15 years, and averaged energy costs for heating and cooling) of a 2,500 square foot home in New York state

Source: Cleantech Group

Cleantech Group

Residential Heat Pumps: Value Chain



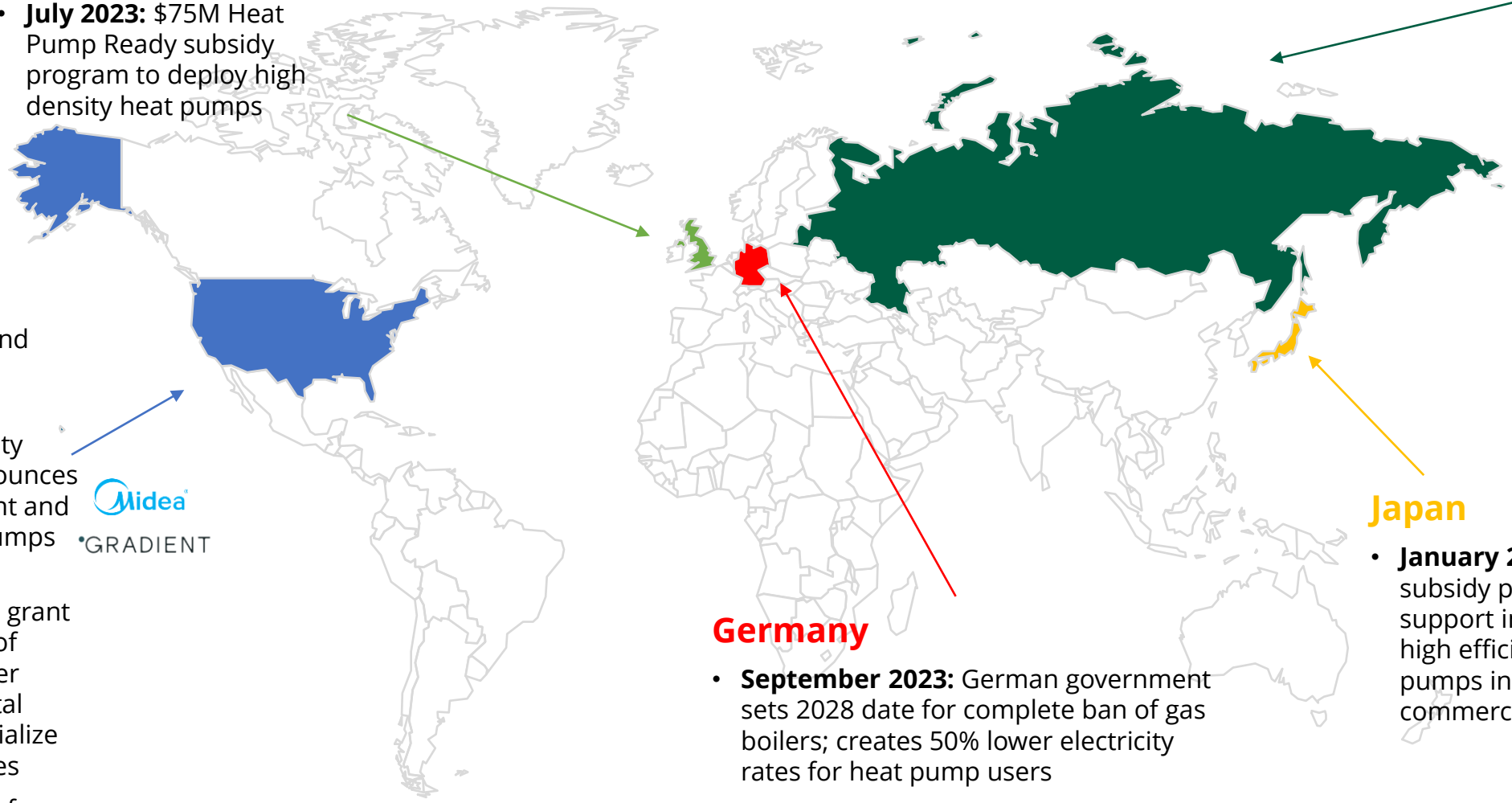
Cleantech Group

Residential Heat Pumps: Regional Drivers

Initially a hopeful long-term solution, regional pressure pushed heat pumps to commercial mainstream

United Kingdom

- **July 2023:** $75M Heat Pump Ready subsidy program to deploy high density heat pumps



United States

- **November 2023:** U.S. Department of Energy announces $169M to accelerate residential and commercial heat pump manufacturing
- **June 2023:** New York City Housing Authority announces $70M deal with Gradient and Midea to install heat pumps across New York City
- **December 2022:** $15M grant from U.S. Department of Energy to Geysers Power Company and Occidental Petroleum to commercialize new drilling technologies
- **April 2022:** $20M grant from U.S. Department of Energy to several drilling companies to research new technologies

Russia

- **August 2022:** Natural gas prices reach their height, up 270% in six months, additional embargos of Russian gas trigger intense investment and demand for heat pumps across Europe

Germany

- **September 2023:** German government sets 2028 date for complete ban of gas boilers; creates 50% lower electricity rates for heat pump users
- **September 2022:** German government announces $3B ground source subsidy scheme to create district heating networks over next 10 years

Japan

- **January 2022:** $309M subsidy program to support introduction of high efficiency heat pumps in residential and commercial properties

Residential Heat Pumps: The ABCs

Consumer demand outstripping both supply and installers technical bandwidth

Attractiveness

Business Models

Competitive Trends

Discussion

- Global residential heat pump market is valued at $8.1B, expected to rise to $11.4B by 2030 (IEA)
- Current growth is rapid in Europe (40% growth last year) while the two largest markets (North America and Asia) growth rates remain steady at around 8-15% a year
- Russia-Ukraine War created natural gas shortages, opening a generational transition in heating infrastructure where gas boilers, furnaces, and radiators are replaced with heat pumps due to high energy pricing and subsidies incentivizing the transition
- Policies mandating heat pump installations (U.S., Germany) in new builds are outstripping heat pump supply from Chinese, European, and American manufacturers, creating openings for innovators

---

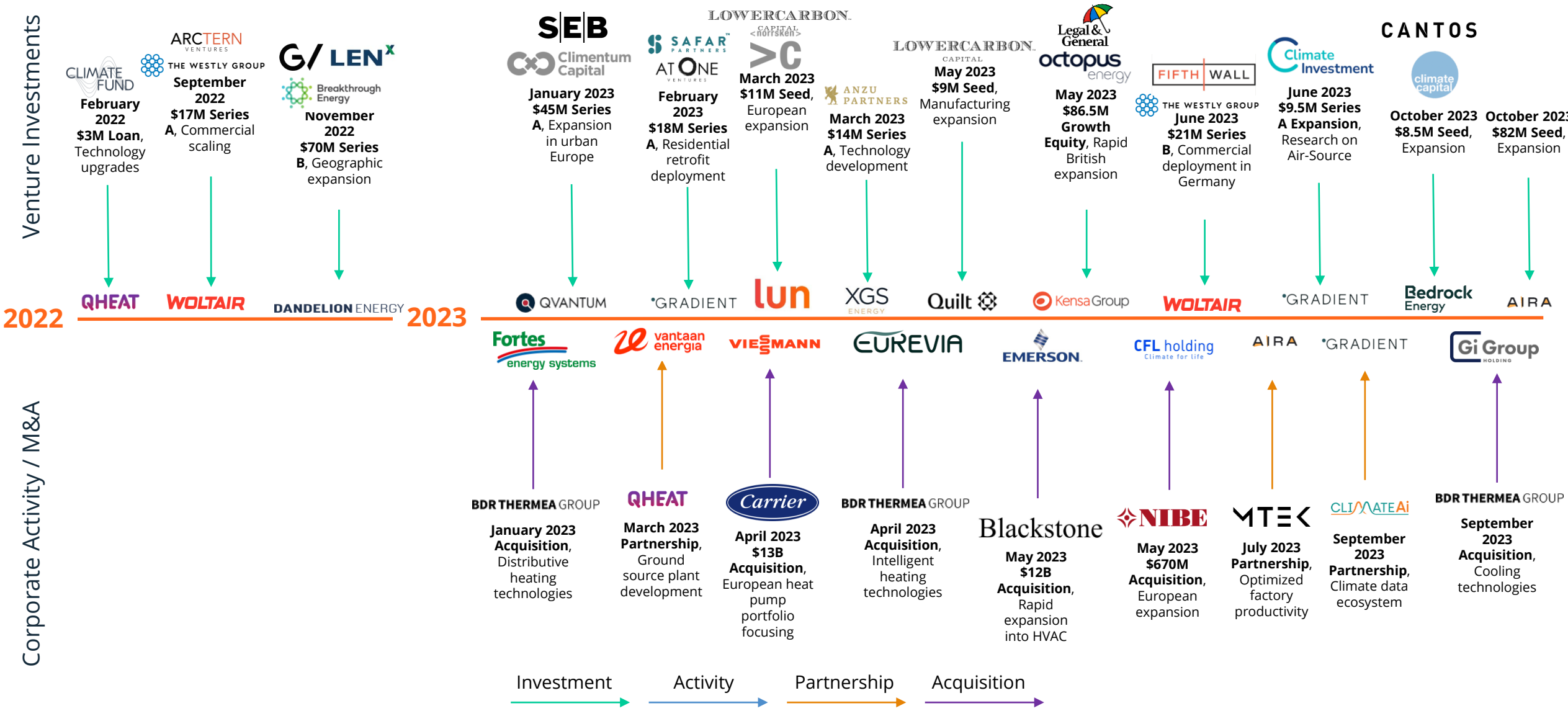
- Original Equipment Manufacturers (**OEM**) succeed with manufacturing scale, granular market fit, and channel partnerships
  - Large OEMs (**NIBE, Daikan, Vaillant**) produce most physical components to be ordered by contractors/consultants (**Dream, Genius Energy Labs**) who have exclusive deals with other construction companies or installers
  - Smaller OEMs (**Gradient, Kelvin**) focus on minimal installation opportunities such as window air source or radiator retrofit units
- Ground source systems avoid retrofitting single units, opt for largest possible clients to spread installation cost
  - Multi-unit suburban homes, full urban buildings, new builds, or community-wide contracts for district systems are optimal markets
  - **Octopus** and **Kensa** pay for all drilling in district systems, pocketing installation grants/subsidies
- Software providers (**Lun, Woltair, Genius Energy Labs**) offer SaaS solutions to expedite installation/surveying processes

---

- Due to technological maturity and price differences, air source makes up about 90% of new heat pumps in Europe contributing to an ultra-congested market, especially compared to ground source
- Massive pain points between planning and installation creating a market for digital planning or entire integration in planning and installation once contractors become more familiar with heat pump technologies
- European manufacturers remain strong due to established installation contracts, American and Chinese hardware is cheaper
- Diverse competition amongst ground source companies in residential space with **Dandelion** focusing on single home projects while **Bedrock** targets urban buildings and **Kensa** creates neighborhood heating with district systems

Residential Heat Pumps: Investment/Corporate Activity

Manufacturers double down on European demand, installers seek to improve timelines



Residential Heat Pumps: Innovator Examples

Innovation in heat pumps is coming across the value chain including drilling depth, modular design, and planning

GeniusEnergyLab

Positioning: Ground source heat pump system designer utilizing AI solutions to optimize large scale heating plans for neighborhoods and urban buildings

Market insight

- Policy incentives are more lucrative for air source than ground source at individual installation level
- Market for ground source has dramatically shifted toward large developments over last five years
- Need for technology to expedite installation/survey

Company insight

- Wide diversity of clients ranging from AECOM to small municipalities
- Filling market gap between manufacturers and installers by expediting site analysis
- Current focus on newly built residential units and subsurface district heating systems

Milestones:

- Extensive IPs and working relationship with Kensa, UK's largest ground source provider
- Trialing new deep drilling technologies alongside oil and gas companies, AI geology mapping tools

Capital: < $1M

Contact: Chris Davidson, CTO

Bedrock Energy

Positioning: Urban ground source drilling and software company using ultra-deep drilling (2,000 feet) for heating/cooling in America

Market insight

- Large spaces cannot transition to air-source heat pumps in a cost-effective manner
- Ground source in single residential units impossible without price reductions in drilling

Company insight

- Deep drilling borrowed from oil and gas industry to create stable temperatures for large units
- Expansion in colder climates where air-source struggles, particularly in America and Scandinavia
- Full integration including planning, drilling, and installation

Milestones:

- Piloting subsurface modeling algorithms for safe urban drilling and autonomous drilling
- Piloting initial urban drilling and heating projects in Texas

Capital: $8.5M

Contact: Silviu Livescu, CTO

GRADIENT

Positioning: Producer of single room window heat pumps intended to replace AC units and radiators in apartments, multifamily homes, schools

Market insight

- Ground source is typically not suitable for urban areas unless it secures multi property deals requiring massive renovations, construction, lengthy timelines, and deep boring
- Traditional air source is too expensive for single unit properties and not efficient for multi unit

Company insight

- Deploying second generation heat pumps in apartment retrofits in American cities
- Unit is cheaper than comparable air source units due to no installation cost, design
- Atomizers for improved cold weather performance

Milestones:

- Great success in securing public investment from Department of Energy and New York City
- Leader in environmentally friendly refrigerants
- Installation can be completed without a technician

Capital: $50M

Contact: Reid Carroll, Investor

Residential Heat Pumps: Innovator Examples

Integrating the heat pump value chain is showing immense promise in cost, timeline reductions

Kensa Group

Positioning: Manufacturer, contractor, and asset manager of ground source heat pumps and their subsurface facets

Market insight

- Commercial properties are a natural fit for ground source, but drilling cost is a major hurdle today
- Single-family homes are a great market, but land availability issues and cost prevent retrofitting in most cases

Company insight

- Global demand for ground source heat pumps is growing but does not warrant international expansion currently
- Will incur drilling cost for district heating to incentivize homeowners, this strategy is most effective in new builds
- Establishing localized, exclusive installer partnerships across Britain

Milestones:

- Development partnership and shared patents with Genius focus on creating massive subsurface heating districts
- Recently launched PREDICT, an AI tool used to modify heat pump performance to specific buildings needs over time to reduce repairs
- Engineering leader in the district heating approach

Capital: $86M

Contact: Matthew Trewhella, Director of Strategic Partnerships

WOLTAIR

Positioning: Provider of installation and planning software for heat pump technicians, manufacturers, and installers to optimize design and cost

Market insight

- Heat pump market in Germany grew by 50% in 2022
- Installers often disagree with manufacturer recommendations or are unfamiliar with new heat pump technologies
- Consumers have difficulty visualizing savings in relation to high cost

Company insight

- Bridging gaps between installers, manufacturers, and customers with personalized design platform, savings/cost calculators
- Recent expansion in Germany was highly successful leading to a 300% growth in installations
- Readily monitoring opportunities in the United States, Canada and actively expanding further into Europe through Italy

Milestones:

- Launched WLTR heat pump as first stand-alone hardware offering
- Major success with software service SuperFix's 2022 launch
- Software solutions increased installation productivity up to threefold

Capital: $42M

Contact: Richard Jaks, Procurement and Supply

Residential Heat Pumps: Keep an Eye Out For…

Air source expedites manufacturing speed to ensure success, ground source requires regulatory support and lower CAPEX

Market Milestones

- Synergy with energy storage and active control of variable energy production from renewables lowers price further while integrating grid management tools
- European manufacturers must bolster output to meet continental demand and reduce reliance on lengthy backlogs in China, US
- Contractors remain hesitant in transitioning from boilers and furnaces, speeding up this transition will reduce installation backlog
- Small innovations in boring (down the hole technology) will have massive effects in the competitiveness of ground source relative to air source in urban markets by 2030
- Integration of manufacturing, planning, and installation remains limited but a possibility through large, regionally dominate groups like **Kensa** and **Octopus Energy**
- Acquisitions of small European manufacturers by American, Chinese companies (**Carrier**) will improve, expand manufacturing output

Innovator Milestones

- OEM to contractor connectivity will be achieved through SaaS targeting installation
- Successful companies will plan for future integration of next-generation refrigerant solutions (**R290 expanding to America**)
- Air source (small technical improvements)
  - Successful urban roll out of window air source units (**BlueHeart, Kelvin**, **Gradient**) must stack improvements in component innovations to reduce OPEX, succeed in suburban markets
  - Future success of air source in cold climates tied to **atomizer** rollout, potential applications of **waste heat capture**, and **semiconductors** to replace compressors
- Ground source (lower CAPEX to dominate suburbs)
  - Ground source companies like **Bedrock** and **Dandelion** must drive down CAPEX costs with boring innovation (hammer/plasma arc systems, priming)
  - **Kensa** looking to roll out district heating systems across UK by 2025

Regulatory/Policy Milestones

- America and China manufacturing dominance continues, bolstered by subsidy policies and import protections
- Japan began dominating IP filings in 2015 and looks to continue this strategy
- The Inflation Reduction Act (IRA), heat pump requirements in new builds, and boiler/furnace bans bolster American demand
- Specific policy needed to subsidize demand for ground source over air source due to high installation cost
- Germany and Holland banned future boiler installations, expect several other nations (Italy, France) to initiate similar policies
- Germany and Holland also trialing cheaper electricity rate pricing for use of heat pumps, success could inspire similar policies globally
- Europe's reliance on imported heat pumps could be drastically curbed with heavy manufacturing subsidies

Residential Heat Pumps: Incumbents

Influence of lobbying has proven very successful in Europe and North America, leading to rapid growth

	Positioning	Engaging Innovation
NIBE	▪ Global manufacturer of heating, cooling, and ventilation appliances for residential and commercial customers ▪ Based in Sweden, NIBE was an early adopter of ground source due to colder climate, now are a leader in the field	▪ Aggressive in acquisitions with Waterkotte, Argoclima, and CFL with strategy of bolstering European markets and manufacturing prowess ▪ Successful lobbying on several pieces of (UK and US) legislation focused on rebate/subsidies for heat pumps ▪ Enjoyed increased stock interest due to European policy incentives on heat pumps, generating massive revenue for research projects on air and ground source
SKANSKA	▪ American construction firm specializing in commercial buildings across the world ▪ Utilize ground source heating systems to provide schools, hospitals, and airports large scale heating without significant operational cost	▪ Conducting internal research on heat and energy storage systems using ground source systems in the United Kingdom and Norway ▪ Leading engagement with geology researchers, drilling companies in identifying temperature ground composition standards for future drilling ▪ Successful lobbying efforts in Washington and Oregon to mandate heat pumps in new builds
Carrier	▪ American manufacturer of HVAC, refrigeration, and fire solutions transitioning their portfolio to focus mostly on heat pumps ▪ Actively expanding into Europe with hope of transferring technology advancement to America	▪ $12B acquisition of Veissmann more than doubled market share by aggressively entering German market, deal to acquire Toshiba's HVAC department bolstered manufacturing ▪ Focus on efficiency in cold climates through improved ductless systems in air source, refrigerants, and distributed heating ▪ Created Technical Training Center to expedite HVAC installers learning curve on heat pumps

On the Radar – New Spin-Outs and Pre-Commercial Innovation

Ecosystem	Source		Innovation
University Spin-Outs	delftenterprises	▪ Delft Enterprises is an accelerator for spinouts of Delft University of Technology	▪ Magneto Systems spun out with help from Delft Enterprises after conducting research on magnetocaloric materials, materials that convert magnetic energy into heat
	Magneto	▪ Magneto Systems is a refrigerant replacement company for heat pump manufacturers	▪ Company now produces alternatives to environmentally hazardous gas refrigerants including manganese, iron, phosphorus, and silicon mesh components currently being tested in Holland
	Department of Chemistry and Chemical Biology, Harvard	▪ The Mason Group at Harvard University's Department of Chemistry focuses on manipulating heat through inorganic chemistry and nanomaterials	▪ Recently published research demonstrating two-dimensional perovskites' ability to release and absorb heat in response to pressure changes ▪ This technology could replace environmentally toxic refrigerants while enhancing heating/cooling ability of heat pumps by replacing traditional vapor-based compressors
Research Spin-Outs	TNO	▪ TNO is a Dutch non-profit research organization focused on sustainable entrepreneurship	▪ Research focused on thermoacoustic properties of expanding a gas, helium, to manipulate temperatures and pass heat through exchangers
	BLUE HEART	▪ BlueHeart Energy is a heat pump manufacturer specializing in thermoacoustic heating	▪ Resulting spin-out, BlueHeart Energy spent seven years in commercial development before launch in 2023 where it has experienced rapid growth and now challenges industry preference of compressors
National Labs	TRANE TECHNOLOGIES	▪ Trane Technologies is an industry leading corporate in the heating, cooling, and refrigeration solutions space	▪ Research focused on creating high temperature heat pumps for industrial and commercial building heating systems ▪ Further research projects on implementation of AI process controls
	Oak Ridge National Laboratory	▪ Oak Ridge National Laboratory specializes in nuclear materials research and other areas of sustainable energy	▪ Additional joint projects in commercializing heat pump technology in manufacturing, waste heat recovery, and food supply chain sectors with Texas A&M and Purdue University

Energy & Power Sector Research

Cleantech Group tracks the start-ups, scale-ups, investors and multinationals from across the region and the world shaping the future of the Energy & Power industry

Recent Published Research

Spotlights

- Plant Protein (Q3 2023)
- Cathodes Manufacturing (Q2 2023)
- eJet (Q2 2023)
- Flood Resilient Infrastructure (Q1 2023)

Upcoming Topics

Update(s)

- Spotlight: Alternative lithium chemistries (Q1 2024)

New

- Insight: Low-carbon Hydrogen (Q3 2023)
- Spotlight: Marine energy (Q3 2023)

Upcoming Events

- **Cleantech Forum North America -** San Diego, U.S. - January 22-24, 2024

Research Analyst – Parker J. Bovée

- Focused on emerging innovation & trends across cleantech sectors, including water, advanced materials, & food science.
- Prior to joining Cleantech Group, Parker developed wildfire prevention technologies with VegaMX and researched wildfire management policy at Duke University and UC Berkeley.
- Parker earned a Bachelor's degree in History and Public Policy from the University of California, Berkeley where he specialized in the history of American environmental entrepreneurship.

Cleantech Group®

Championing Sustainable Innovation, Catalyzing Business Opportunities

Since 2002, our Research, Consulting and Events have propelled opportunities for sustainable growth powered by innovation to thrive in a more digitized, decarbonized, and resource-efficient future.

Contact us at research@cleantech.com